NDT TECHNIQUES FOR DETERMINING DEPTH OF FOUNDATIONS

Sanjay Gupta[1], Ravi Sundaram[2], Sorabh Gupta[3]

ABSTRACT

Evaluating the depth of existing foundations may sometimes be required on construction projects. If original pile records / drawings are not available, it may become difficult to make a rational assessment of the depth of existing foundations. Where the new construction requires knowledge of length of pile / depth of existing foundation, modern NDT techniques such as parallel seismic and sonic echo / impulse response tests can provide useful information.

The parallel seismic method involves impacting the exposed substructure to generate seismic wave energy that travels down the foundation which is sensed by a receiver in a nearby borehole. The sonic echo response test involves measurement of the echoes (reflections) of compression (longitudinal) stress waves from the pile tip.

The paper presents a case study demonstrating application of NDT methods to assess the depth of pile foundations installed for an existing railway bridge. The information was required for construction of an underground metro tunnel crossing the bridge alignment.

To assess the pile length at the bridge abutment location, excavation was carried out to expose the pile cap. A borehole was drilled adjacent to the pile cap to 25 m depth and a PVC casing was placed and grouted in the hole. Parallel seismic test was conducted by impacting the pile cap with a hammer and recording the response in a geophone placed at different depths in the borehole. As a cross-check, sonic echo response test or low-strain pile integrity test was performed by striking the pile using a small hand-held hammer and measuring the response using an accelerometer placed on the pile cap.

The evaluation of the data indicated that the pile length may be about 12-13.4 m below the pile cap. The sonic echo impulse test (pile integrity test) suggested variations in pile diameter with bulging at about 3 m depth. Considering limitations of NDT methods, the authors suggest that the actual pile length be considered to be about 11 to 14 m. The sketch on Fig. 1 below summarizes the results

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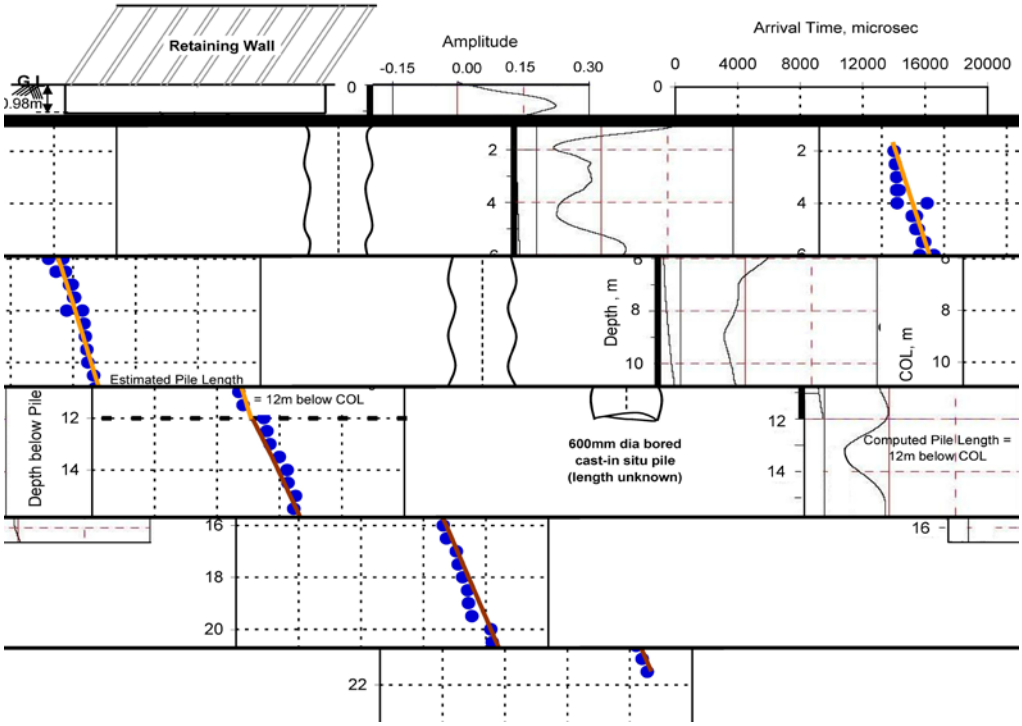

Fig. 1 Pile Length interpreted from Sonic Echo Response and Parallel Seismic Test

Keywords: Unknown foundation depth, NDT Testing, Parallel seismic test, sonic echo response test, pile foundations

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ABSTRACT: Non-destructive tests such as parallel seismic test and sonic echo response test can assist in assessing the depth of an old / unknown foundation. The paper presents a case study where it was required to assess the length of pile below a bridge abutment for construction of a metro tunnel. To conduct the parallel seismic test, a borehole was drilled adjacent to the pile cap and the pile cap was struck with a hammer. Geophones placed in the borehole at different depths were used to study the response. In the sonic echo response test, the response to an impact on the pile is evaluated to assess the pile depth. The study indicated the pile length to be about 11 to 14 m below the pile cap.

INTRODUCTION

Determining the depth of existing foundations may be required where new construction adjoins existing structures. It may also be needed when adding to the superstructure, upgrading structural loads, investigating settlement or scour, or superstructure replacement.

Where original piling records or drawings are not available, rational evaluation of the existing foundations presents a veritable challenge to the geotechnical engineer.

Conventional methods of investigating unknown foundations such as excavation, probing, coring, etc. are often expensive, destructive, impractical or limited in their application.

The current state-of-practice of non-destructive determination of unknown foundation conditions primarily [1] involves two methods:

- Borehole Parallel Seismic method, and
- Sonic Echo / Impulse Response test.

These methods can be effectively used to make a reasonable assessment of the foundation depth and also make a qualitative assessment of the concrete quality.

Other available NDT methods such as Bending Wave, Ultra-seismic, Spectral Analysis of Surface Waves, Borehole Radar and Induction Field tests are still in the development stage, and the results are debatable.

The paper presents a case study demonstrating application of NDT methods to assess the depth of pile foundations installed for an existing railway bridge. The pile depth was required for construction of an underground metro tunnel crossing the bridge alignment.

PROJECT DETAILS

The metro tunnel shall cross an existing railway line. There is a retaining wall at this location. Railway drawings shown to us on site indicate the presence of pile foundations underneath the abutment retaining wall. However, the as-constructed drawings for the bridge were not available. As per unconfirmed information from Railway sources, the piles were expected to extend to about 9-16 m depth below the cap level. Figure 1 presents a photograph of the bridge.

Fig. 1 A view of the bridge

EXCAVATION TO EXPOSE PILES

Manual excavation was done to expose the pile cap. The top part of the corner pile was also exposed. The excavation revealed that beneath the abutment wall, the pile cut-off level was 0.96 m below ground level. The pile diameter was measured to be 0.6 m. Figure 2 presents a view of the exposed pile below the brick masonry floor.

Fig. 2 Trial pit showing exposed pile

NDT TESTS

To assess the depth of the piles, the pulse echo response test and the parallel seismic tests were performed. The test methodologies are briefly explained below.

Parallel Seismic Test

The borehole Parallel Seismic (PS) method was developed specifically to determine the depths of unknown foundations. It can be effectively used on sites where the foundation top is not accessible [2]. The test involves impacting the exposed sub-structure to generate seismic wave energy that travels down the foundation and is sensed by a hydrophone or geophone receiver in a nearby borehole.

An impact to the exposed structure generates wave energy that travels down the foundation. It is tracked along the depth with receivers in a nearby parallel borehole. When the average velocity slows down, it indicates the receiver has gone beyond the bottom of the foundation, and thus, the depth is determined. A schematic of the test is illustrated on Fig. 3.

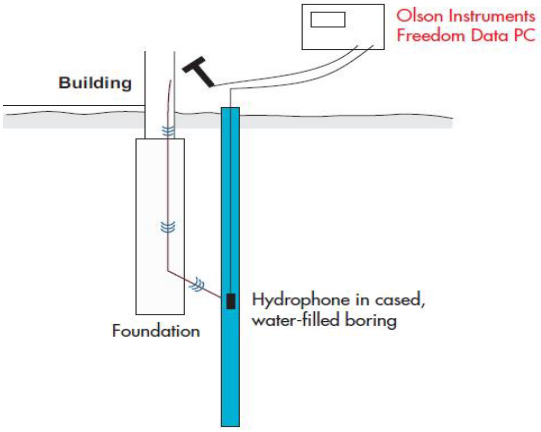

Fig. 3 Schematic of parallel seismic test

The data was processed using the WinGeo software for picking the first arrival of the compression wave. The data is then analyzed in the time domain.

The first arrival times are plotted as a function of depth. The change of slope of the graph corresponds to the depth of the foundation.

Sonic Echo Response Test

The test involves measurement of the echoes (reflections) of compression (longitudinal) stress waves from foundation bottom / pile tip. The test, developed for quality assurance of the integrity and length of newly constructed piles, has been adapted for assessing the depth of the existing foundation.

The top of the pile is hit with a small hand-held hammer. An acoustic wave from the impact propagates down through the pile. Variations in shape and material quality of the pile produce reflections, which are observed as they return to the surface [3,4]. Reflections are then interpreted, considering their nature and times of observation, to assess pile integrity.

TEST RESULTS

Pile Length from Parallel Seismic Test

A 3.7 kg hammer was used to impact the pile foundation. Tests were carried out by impacting the top of the pile cap, as well as directly on the exposed pile shaft.

Two down-hole triaxial geophones at 1.5 m spacing were used to receive the compression and shear waves traveling down the foundation. Measurements were taken at every 0.5 m depth interval to the final borehole depth of 25 m below grade. A photograph of the test set-up is illustrated on Fig. 4.

Fig. 4 Parallel seismic test set-up

A plot of the interpreted first-arrival time versus depth below pile cut-off-level is presented on Fig. 5. As shown on this plot, there seems to be a clear break in the seismic wave velocity at about 12 m depth below the pile cut-off-level.

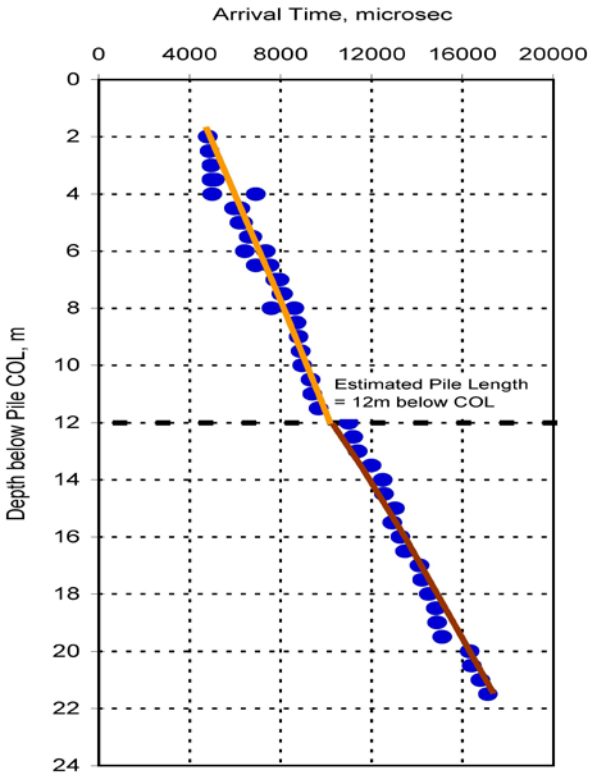

Fig. 5 Parallel seismic test results

Reflection from Sonic Echo Response Test

Low-strain pile integrity tests (PIT) were carried out at the project site using 1.3 kg and 3.7 kg hammers. A heavier hammer produces lower frequency pulses which travel further but produce reflections that are less clearly defined and therefore more difficult to read. A photograph of the test is presented on Fig. 6.

Fig. 6 Sonic echo response test in progress

Attempts were made to collect data by impacting the top of the pile cap, as well as the pile shaft

directly. However, the results of the former were unclear, probably due to the presence of brick masonry around the pile cap.

Typical PIT results obtained by impacting the pile shaft directly using a 1.3 kg hammer are presented on Fig. 7.

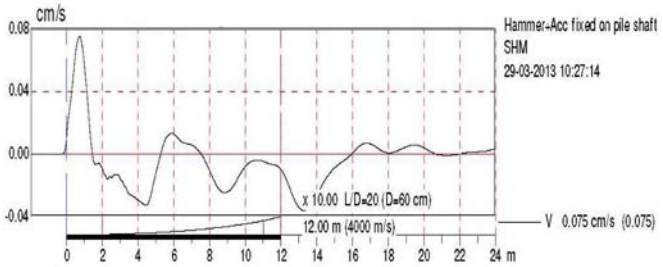

Fig. 7 Sonic echo response data (time domain)

A frequency response analysis was also conducted on selected records, as shown on Fig. 8.

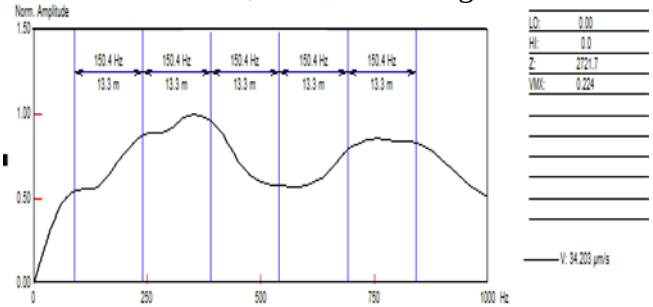

Fig. 8 Sonic echo response data (frequency domain)

The analysis of the pulse echo data indicates a pile length of about 13.3 m.

Estimated Pile Length

The results of the NDT tests conducted on site are summarized in Table 1 below:

Table 1 Interpreted Pile Length

Test	Pile Length below COL
Parallel Seismic Test	12 m
Sonic Echo Test	13.3 m

In view of the inherent limitations of NDT testing, the length of the tested pile may be considered to be about 11-14 m below the pile cap.

A combined plot of the pulse echo response and the parallel seismic test results is illustrated on Fig. 9, along with a schematic sketch of the interpreted foundation system.

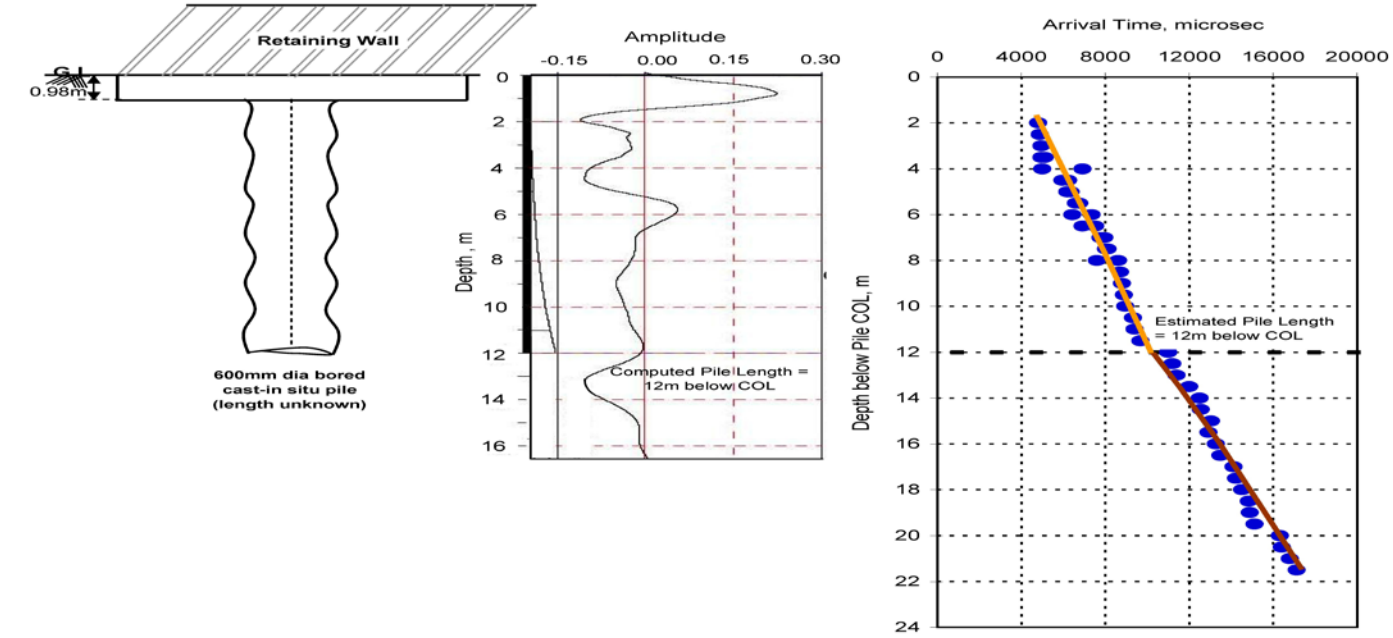

Fig. 9 Combined NDT results

Limitations of the test

Like all NDT methods, both tests have several limitations. The success / efficacy of the method depends upon the soil conditions, building characteristics, site conditions, etc.

The quality of results from the parallel seismic test depends on the following:

- difference in the velocity of wave in the concrete and the surrounding soil,
- spacing between the borehole and the foundation element, and
- access to the foundation.

The sonic echo response test has the following limitations:

- The method is generally applicable if the pile length not more than 30 pile diameters,
- The interpreted pile length depends on assumed wave speed, soil strength, pile uniformity, actual diameter and length, equipment noise, filters and resolution, and
- Highly non-uniform piles with large variations in diameter and concrete quality are difficult to interpret.

CONCLUDING REMARKS

Non-destructive tests such as parallel seismic tests and sonic echo response test can be effectively used to assess the depth of existing / unknown foundations. The paper presents a successful case study of evaluation of depth of pile of a bridge abutment below which a metro tunnel was planned. The study indicates that the pile length is likely to be about 11-14 m below the pile cap. It is important to recognize the limitations of the techniques and design the tunnel accordingly.

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